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Research Article

Properties and Applications of Nanodiamond Nanocomposite

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Abstract:
Nanodiamond is a unique zero-dimensional nanocarbon structure havinghigh surface areas, mechanical features, optical properties, electronic properties, chemical properties, and tunable surface characteristics. Several techniques involving high pressure and temperature have been used for the synthesis of micro- and nano-crystalline diamond particles. Surface doping and introduction of functional groups may help to alter the optical, electronic, mechanical, and chemical properties of nanodiamond structures. Owing to non-toxicity and biocompatibility, nanodiamond-based nanocomposite are suitable for biomedical applications such as bioimaging, drug delivery, and tissue engineering. Other technological applications of nanodiamond nanocomposite are for mechanical and thermal solicitations, and electrical and electrochemical applications.

Keywords: Nanodiamond; nano-crystalline; electronic; biomedical

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1. Introduction

Nanodiamond (ND) is a member of diverse nanocarbon family [1]. Individual nanodiamondnanoparticlehas size of 4-5 nm. Shape of nanodiamond nanoparticles is spherical or elliptical. ND surface consists of variety of functional groups such as phenols, carboxylic acid, sulfonic acid, hydroxyl, epoxide groups, etc. [2, 3]. Nanodiamond was produced by detonation method in 1960s [3]. Detonation synthesis of nanodiamond involves mixture of trinitrotoluene and hexogen or octogen. The major breakthroughs about ND were found in 1990s [4, 5]. Nanodiamond have advantages of inexpensive and large-scale synthesis, facile surface functionalization, non-toxicity, biocompatibility, and excellent mechanical (hardness), optical, electronic, and thermal characteristics [6, 7]. Initially, nanodiamond nanoparticles have been used in polishes and engine oil additives to enhance lubrication. Polymer-based nanodiamond nanocomposite possess several advance strength applications [8]. These nanocomposite have also been utilized in electrical and electrochemical applications [9]. Nanodiamond nanoparticles of ~5 nm possess large accessible surface and tailorable surface chemistry to be employed in drug delivery. Fluorescent nanodiamond nanocomposite have found application for biomedical imaging [10]. Moreover, nanodiamond possess less toxicity compared with other carbon nanoparticles, so has been efficiently used in biomedical imaging, drug delivery, and nanomedicine Here, purity of nanodiamond, alteration in surface chemistry, dispersability in matrix, and nanocomposite composition affect the overall nanomaterial properties and end application.

2. Synthesis of nanodiamond

Naturally, nanodiamond nanoparticles are present in planetary systems like stars due to cosmic sources. The most important method for the synthesis of nanodiamond is detonation synthesis(Fig. 1). In this method, 60 wt.% explosive i.e. trinitrotoluene ($C_6H_2(NO_2)_3CH_3$) and 40 wt.% hexogen ($C_3H_6N_6O_6$) are detonated in metallic chamber at high atmosphere 4500 K (N_2, CO_2, H_2O).

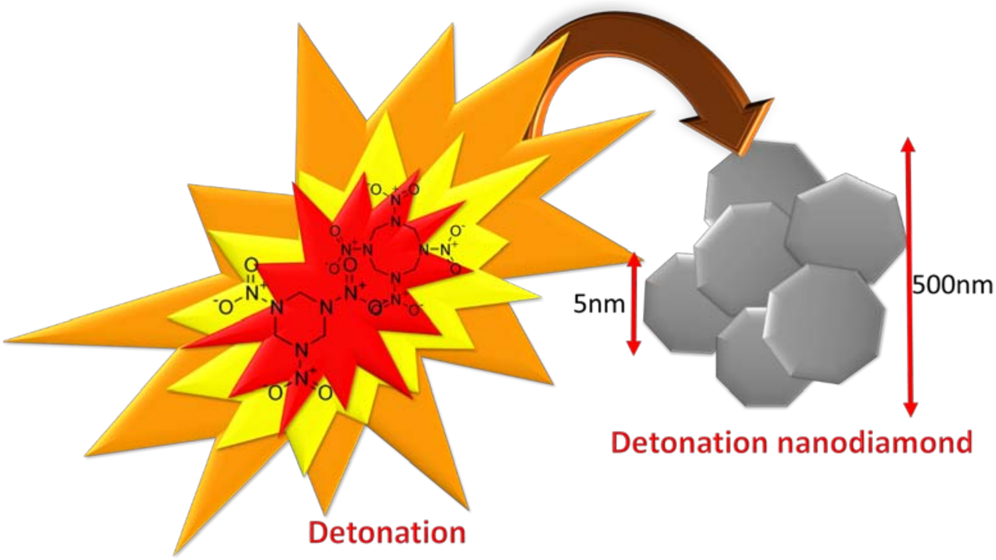

Fig. 1 Detonation synthesis of nanodiamond.

After detonation process, diamond soot is collected from the chamber. The product is the mixture ofnanodiamond particles and graphitic carbon forms [11, 12].Liquid carbon clusters of 1-2 nm may be observed. Purification techniques have also been used to get rid of impurities. Among other techniques, plasma-assisted chemical vapor deposition (PACVD), laser ablation, ball milling, autoclave synthesis, ion irradiation of graphite, etc. have been used [13, 14]. Properties and applications of nanodiamond obtained with size of 2-10 nm have been focused in literature [15].

3. Properties of nanodiamond

Nanodiamond is actually a mixture of sp^2 and sp3 carbon atoms (Fig. 2). There are three notable parts of nanodiamond structure *(i)* core of nanodiamond nanoparticle consisting of sp^3 hybridized carbon; *(ii)* inner shell of sp^2 hybridized carbon around core; and *(iii)* outer surface with functional groups. Nanodiamond has spherical or elliptical shape [16]. It has capability to deliver bulk diamond properties at nanoscale. ND possess superior Young's modulus, hardness, optical properties, fluorescence, chemical stability, thermal conductivity, and biocompatibility. Electronic properties of nanodiamond have been studied using x-ray absorption near-edge studies. Quantum confinement effects were also observed ~5 nm. Nanodiamond band gap was found smaller than diamond with broad luminescence of 380-520 nm. Fluorescence effects of nanodiamond have been found significant in high-resolution magnetic sensing, resonance energy transfer, and biomedical imaging. Biocompatibility and non-toxicity render them useful for drug delivery and nanomedicine. Another important way to enhance the properties of nanodiamond is compositing [18-25]. For polymeric nanocomposite formation, solubility behavior of ND is definitely important [26-31]. A comparative effect of various solvents on the solubility behavior of nanodiamond is given in Table 1. Properties of polymer/ND nanocomposite greatly vary compared with the polymer/CNT and polymer/graphene nanocomposite [32-41].

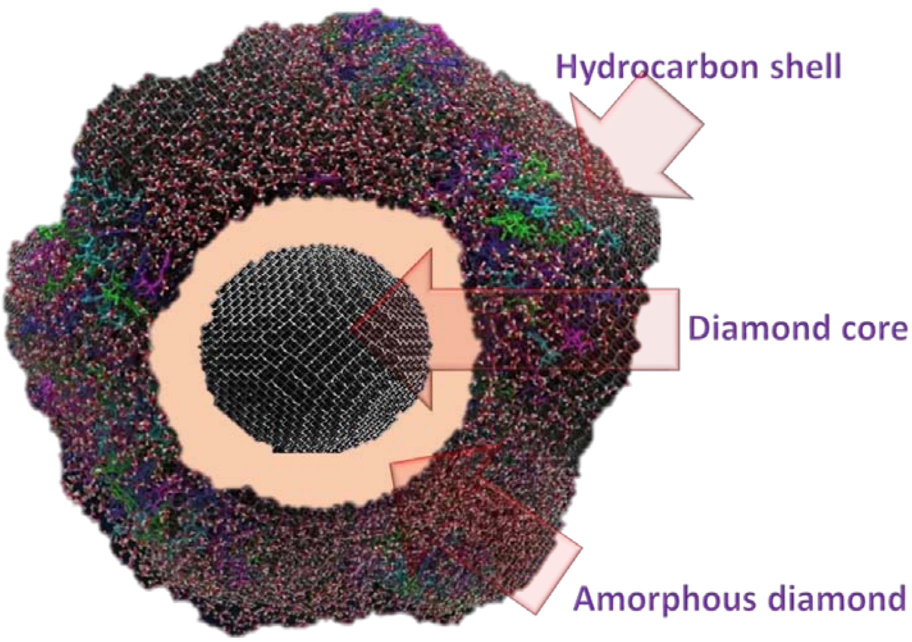

Fig. 2 Structure of nanodiamond**.**

Table 1 Solubility behavior of ND in various solvents.

Solvent	Nanodiamond (mg/L)	Functional-ND (mg/L)
Tetrahydrofuran	>5	>50
Chloroform	~5	<45
Ethanol	>20	<50
Water	>20	<50

4. Surface modification of nanodiamond

Surface chemistry of nanodiamond nanoparticle is quite difficult to understand. Carboxylic groups (ND-COOH), hydroxyl group (ND-OH), aldehyde (ND-CHO), carbonyl (ND-C=O), nitrogen containing groups (ND-NH_2, ND-C• N), and several additional groups (ND-C–F, ND-CH) are present on nanodiamond surface [42, 43]. Carboxylic, carbonyl, and hydroxyl groups can be generated on ND surface using strong acids. Heating in NH_3 may generate nitrogen containing functionalities on ND surface. Heating in the presence of Cl_2 and F_2 may also introduce relevant functionalities on nanodiamond. Thus, wide range of surface groups can be fashioned on nanodiamond using wet chemistry (Fig. 3).

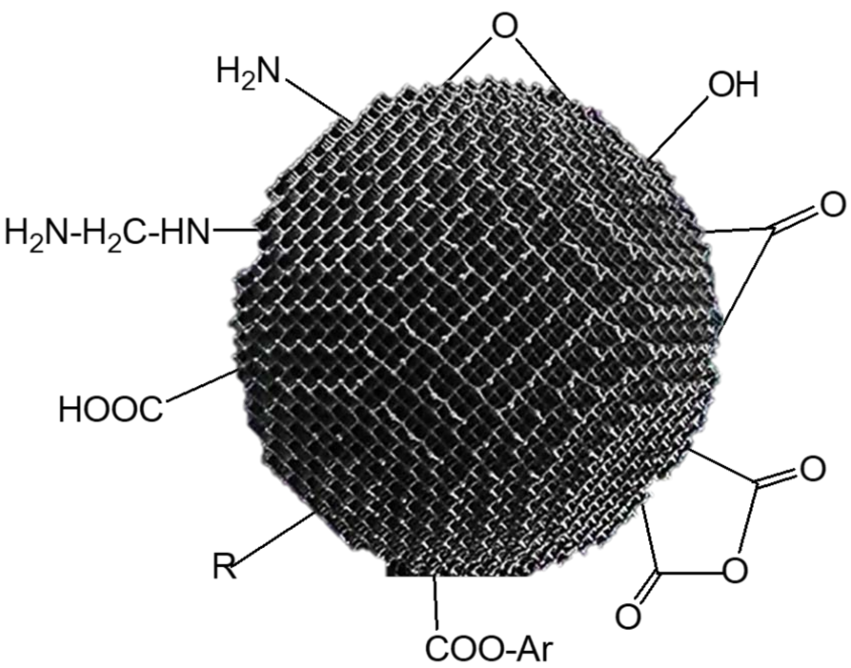

Fig. 3 Surface modification of nanodiamond.

5. Application areas of nanodiamond nanocomposite

5.1 Nanocomposite:Mechanical and thermal solicitations

Superior mechanical and thermal properties of nanodiamond render them excellent nanofiller material for nanocomposite. Mechanical strength, wear resistance, adhesion, thermal stability, and thermal conductivity have found to improve with nanofiller loading in polymers [44]. Improvement in mechanical and thermal degradation properties need well-dispersed and functionalized nanodiamond reinforcement. Mechanical properties of epoxy/ND and poly(vinyl alcohol)/ND nanocomposite have been improved with small amount of nanodiamond [45]. Young's modulus of nanodiamond may increase several times compared with the neat polymer. Interfacial interaction between matrix/nanofiller may also improve nanodiamond dispersion. Hence, further improvement in mechanical properties can be observed using modified nanodiamond nanofiller. Polymer/nanodiamond nanocomposite with enhance mechanical and thermal properties is a rapidly growing area of research. Fig. 4 shows applications related to improved mechanical and thermal properties of polymer/nanodiamond nanocomposite. These nanocomposite with dispersed nanodiamond have been developed using various techniques, and are desirable for advance future applications.

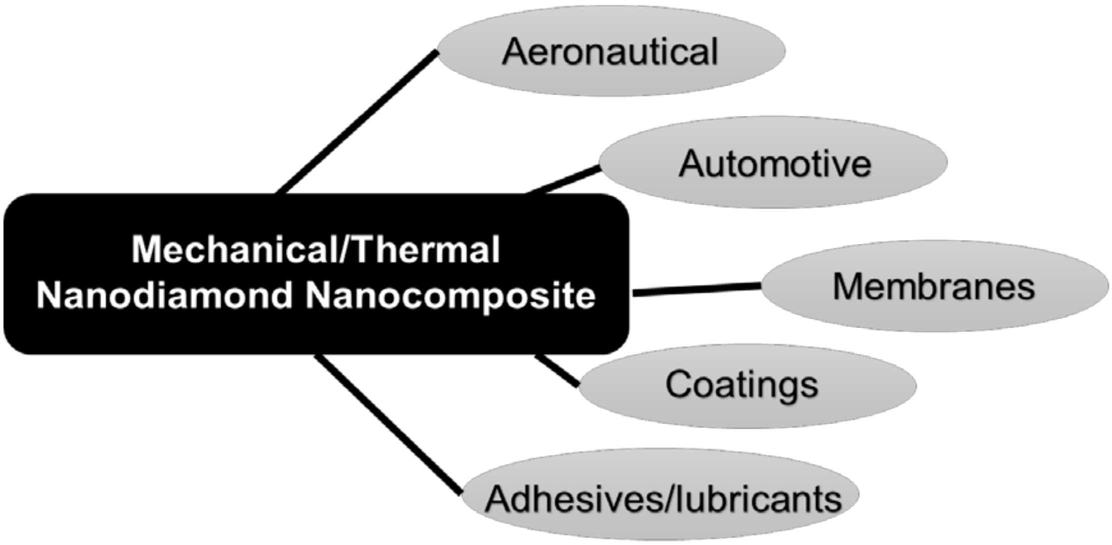

Fig. 4 Applications of polymer/nanodiamond nanocomposites.

5.2 Electrical and electrochemical applications

Electrical and electrochemical properties of nanodiamond and polymer/ND nanodiamond have been used for various applications [46]. Nanodiamond coated electrodes have been applied in sensors. Nanocomposite-based on nitrogen-doped detonation nanodiamond has been used in quantum computing, quantum coherent devices, semiconductor device, and microelectromechanical systems (MEMS) [47, 48]. Nanocrystalline diamond nanocomposite has been analyzed using Raman scattering spectroscopy, electrochemical response, scanning electron microscopy, and cyclic voltammetry measurements. Boron doped nanodiamond has also been used in these materials. The polymer/ND may have high capacitance values of 230-990 μFcm^{-2}.

5.3 Biomedical applications

The detonation nanodiamond has recently been focused as promising material for biomedical applications. Nanodiamond-based materials are capable of meeting several biomedical requirements [49, 50].Polymer/nanodiamond nanocomposite have fine biocompatibility, so used in tissue scaffolds and surgical implants. They are used to form mechanically robust implants. Hardness and Young's modulus of such bioimplants have been found closer to natural human bone. Polymer/nanodiamond nanocomposite act as platform for growth of protein-coated materials [51]. These nanocomposite has been employed to deliver drugs and biologically active molecules owing to biocompatible and bioresorbable nature. Drug delivery podium involves ability to carry broad range of therapeutics, dispersability, and scalability in desired medium. These materials also have potential for bioimaging.

6. Conclusion

Nanodiamond is an important type of nanocarbon. It has been prepared using various techniques. Owing to exceptional optical, electronic,and mechanical properties, nanodiamond forms rapidly growing field of nanocomposite. This review addresses basic knowledge about structure, properties and applications of nanodiamond and ND-derived nanocomposite.ND is a promising nanofillercandidate for technical applications demanding improved mechanical and thermal stability. Conducting polymer/ND nanodiamond offers applications in electronic devices, quantum coherent devices, semiconductor devices, and microelectromechanical devices. Polymer/nanodiamond nanocomposite also found potential in tissue engineering, drug delivery, bioimaging, etc. However, these materials offer great challenges and potential for future research in this field.

Reference

1. Danilenko VV. On the history of the discovery of nanodiamond synthesis. ***Phys Sol State***. 2004, 46:595-599
2. Zheng WW, Hsieh YH, Chiu YC, Cai SJ, Cheng CL, Chen C. Organic functionalization of ultradispersed nanodiamond: synthesis and applications. ***J Mater Chem***. 2009, 19:8432-8441
3. Kausar A. Structure and chemistry of polymer/nanodiamond composites. ***InHybrid Polymer Composite Materials***. 2017, 1:pp. 1-21
4. Kausar A. Amalgamation of Nanodiamond and Epoxy. ***Am JPolymSci Engineer***. 2017, 5:34-42.
5. Khan DM, Kausar A, Saeed A. Research Advancement Towards Polymer/Nanodiamond Composite in Buckypaper: A Review. ***Polym-PlastTechnol Engineer***. 2017, 56:946-965
6. Kausar A. A Study on Waterborne Polyurethane Coated Polyamide 11 Fiber and Composite Fiber with Nanodiamond. ***Int J Mater Chem***. 2015;5:101-105
7. Kausar A, Ashraf R, Siddiq M. Polymer/nanodiamond composites in Li-ion batteries: A review. ***Polym-PlastTechnol Engineer***. 2014, 53:550-563
8. Kausar A, Rafique I, Muhammad B. Electromagnetic Interference Shielding of Polymer/Nanodiamond, Polymer/Carbon Nanotube, and Polymer/Nanodiamond–Carbon Nanotube Nanobifiller Composite: A Review. ***Polym-PlastTechnol Engineer***. 2017, 56:347-363.
9. Kausar A. Nanodiamond: a multitalented material for cutting edge solar cell application. ***Mater Res Innovat***. 2018, 22:302-314

10. Kausar A. Nanodiamond reinforcement in polyamide and polyimide matrices: Fundamentals and applications. ***J Plast Film Sheet.*** 2018, p.8756087918773521
11. Greiner NR, Phillips D S, Johnson J D, Volk F. Diamonds in detonation soot. ***Nature***.1988, 333:440-442
12. Kausar A, Ilyas H, Siddiq M. Current Research Status and Application of Polymer/Carbon NanofillerBuckypaper: A Review. ***Polym-PlastTechnol Engineer***. 2017, 56:1780-1800
13. Kausar A. Nanocarbon-based Nanocomposite in Green Engineering. ***Res J Nanosci Engineer***. 2018, 2:28-33
14. Kausar A. A Study on Poly(vinyl alcohol-co-ethylene)-graft-Polystyrene Reinforced with Two Functional Nanofillers. ***Polym-PlastTechnol Engineer***. 2015, 54:741-749
15. Jabeen S, Kausar A, Muhammad B, Gul S, Farooq M. A review on polymeric nanocomposites of nanodiamond, carbon nanotube, and nanobifiller: Structure, preparation and properties. ***Polym-PlastTechnol Engineer***. 2015, 54:1379-1409
16. Danilenko VV. In Synthesis, Properties and Applications of Ultrananocrystalline Diamond (Proceedings of NATO Advanced Research Workshop), Gruen D, Shenderova O, Vul A, Eds,pp. 181-198
17. Kausar A, Ashraf R. Electrospun, non-woven, nanofibrous membranes prepared from nano-diamond and multi-walled carbon nanotube-filled poly (azo-pyridine) and epoxy composites reinforced with these membranes. ***J Plast Film Sheet***. 2014, 30:369-387
18. Kausar A. Polyamide-grafted-multi-walled carbon nanotube electrospun nanofibers/epoxy composites. ***Fiber Polym***. 2014, 15:2564-2571
19. Ashraf R, Kausar A, Siddiq M. Preparation and properties of multilayered polymer/nanodiamond composites via an in situ technique. ***JPolym Engineer***. 2014, 34:415-429
20. Ashraf R, Kausar A, Siddiq M. Preparation and properties of layered carbon nanotube/polyazopyridine/nanodiamond composites. J Plast Film Sheet. 2014, 30:412-434
21. Khan DM, Kausar A, Salman SM. Exploitation of nanobifiller in polymer/graphene oxide–carbon nanotube, polymer/graphene oxide–nanodiamond, and polymer/graphene oxide–montmorillonite composite: A review. ***Polym-PlastTechnol Engineer***. 2016, 55:744-768
22. Kausar A. Nanodiamond tethered epoxy/polyurethane interpenetrating network nanocomposite: Physical properties and thermoresponsive shape-memory behavior. ***Int J PolymAnal Characterizat***. 2016, 21:348-358.
23. Kausar A. Nanodiamond/mwcnt-based polymeric nanofiber reinforced poly (bisphenol a-co-epichlorohydrin). ***Malaysian Polym J***. 2015, 10:23-32
24. Kausar A. Polyaniline composites with nanodiamond, carbon nanotube and silver nanoparticle: Preparation and properties. ***Am JPolymSci Engineer***. 2015, 3:149-160
25. Kausar A. Thermal and rheological properties of waterborne polyurethane/nanodiamond composite. ***NanosciNanotechnol***. 2016, 6:6-10
26. Kausar A. Design of Polydimethylsiloxane/Nylon 6/Nanodiamond for Sensor Application. ***Int J Instrumentat Sci***. 2016, 5:15-18
27. Kausar A. Formation and properties of poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate)/polystyrene composites reinforced with graphene oxide-nanodiamond. ***Am J Polym Sci***. 2014, 4:54-62
28. Kausar A. Properties of Sol-gel Coated Fibers of Polyamide 6/12/Polyvinylpyrrolidone/Nanodiamond. ***Int J Mater Chem***. 2015, 5:91-95

29. Kausar A. Poly (bisphenol A-co-epichlorohydrin) and Nanodiamonds/Poly (azo-pyridine)/Polyamide/Multi-walled Carbon Nanotube-based Nanofiber Nanocomposites. Am ***J PolymSci Engineer***. 2014, 2:35-50
30. Kausar A. Mechanical and Thermal Properties of Polyamide 1010 Composites Filled with Nanodiamond/Graphitized Carbon Black Nanoparticles. ***Am J PolymSci Engineer***. 2015, 3:161-171
31. Kausar A. Performance of Epoxy and Nanodiamond Exfoliated Montmorillonite Nanocomposite. ***Int J Aerospac Sci***. 2016, 4:9-13
32. Nasir A, Kausar A, Younus A. Polymer/graphite nanocomposites: Physical features, fabrication and current relevance. ***Polym-PlastTechnol Engineer***. 2015, 54:750-770
33. Kausar A, Ur Rahman A. Effect of graphene nanoplatelet addition on properties of thermo-responsive shape memory polyurethane-based nanocomposite. ***Fuller Nanotub Carb Nanostruct.*** 2016, 24:235-242
34. Shah R, Kausar A, Muhammad B. Characterization and Properties of Poly (methyl methacrylate)/Graphene, Poly (methyl methacrylate)/Graphene oxide and Poly (methyl methacrylate)/p-Phenylenediamine-Graphene Oxide Nanocomposites. ***Polym-PlastTechnol Engineer***. 2015, 54:1334-1342
35. Kausar A. Estimation of thermo-mechanical and fire resistance profile of epoxy coated polyurethane/fullerene composite films. ***Fuller Nanotub Carb Nanostruct.*** 2016, 24:391-399
36. Kausar A. Investigation on self-assembled blend membranes of polyethylene-block-poly (ethylene glycol)-block-polcaprolactone and poly (styrene-block-methyl methacrylate) with polymer/gold nanocomposite particles. ***Polym-PlastTechnol Engineer***. 2015, 54:1794-1802
37. Kausar A. Performance of polyaniline doped carbon nanotube composite. ***Am J PolymSci Engineer.*** 2017, 5:43-52
38. Khan DM, Kausar A, Salman SM. Fabrication and characterization of polyvinyl chloride/poly (styrene-co-maleic anhydride) intercalated functional nanobifiller-based composite paper.***Int JPolym Anal Characterizat.*** 2016, 21:228-243
39. Kausar A. Carbon nano onion as versatile contender in polymer compositing and advance application. ***Fuller Nanotub Carb Nanostruct.***2017, 25:109-123.
40. Kausar A. Influence of Multi-walled Carbon nanotube on Physical Properties of Epoxy/Cement Nanocomposite. ***Am JNanosciNanotechnol Res.*** 2015, 3:41-50
41. Kausar A. Review on Structure, Properties and Appliance of Essential Conjugated Polymers. ***Am J PolymSci Engineer***. 2016, 4:91-102
42. Krueger A, Lang D. Functionality is key: recent progress in the surface modification of nanodiamond. ***AdvFunct Mater***. 2012, 22:890-906
43. Mochalin VN, Shenderova O, Ho D, Gogotsi Y. The properties and applications of nanodiamonds. Nature Nanotechnol. 2012, 7:11
44. Shenderova O. Detonation nanodiamond and onion-like carbon: Applications in composites. ***Phys. Status Solidi***. A2008, 205:2245-2251
45. Morimune S, Kotera M, Nishino T, Goto K, Hata K. Poly(vinyl alcohol) nanocomposites with nanodiamond. ***Macromolecules***. 2011, 44:4415-4421
46. Portet C, Yushin G, Gogotsi Y. Electrochemical performance of carbon onions, nanodiamonds, carbon black and multiwalled nanotubes in electrical double layer capacitors. Carbon. 2007, 45:2511-2518

47. Ferreira NG, Azevedo AF, Beloto AF, Amaral M, Almeida FA, Oliveira FJ, Silva RF. Nanodiamond films growth on porous silicon substrates for electrochemical applications. ***DiamRelat Mater***. 2005, 14:441-445
48. Kausar A. Polymer/Silver Nanoparticle Nanocomposite as Antimicrobial Materials. ***Frontiers Sci.***2017, 7:31-35
49. Chen M. Nanodiamond vectors functionalized with polyethylenimine for siRNA delivery. ***J Phys Chem Lett***. 2010,1:3167-3171
50. Huang H, Pierstorff, E., Osawa, E, Ho D. Active nanodiamond hydrogels for chemotherapeutic delivery. ***Nano Lett.***2007, 7:3305-3314
51. ThalhammerA,Edgington R J, Cingolani L A, Schoepfer R, Jackman R B. The use of nanodiamond monolayer coatings to promote the formation of functional neuronal networks. *Biomaterials*. 2010, 31;2097-2104